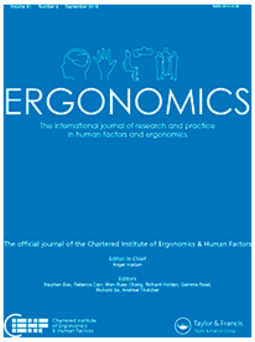


EXHIBIT 18

ERGONOMICS

ISSN: 0014-0139 (Print) 1366-5847 (Online) Journal homepage: https://www.tandfonline.com/loi/terg20

Isometric and isokinetic testing of lifting strength of males in teamwork

WALDEMAR KARWOWSKI & ANIL MITAL

To cite this article: WALDEMAR KARWOWSKI & ANIL MITAL (1986) Isometric and isokinetic testing of lifting strength of males in teamwork, ERGONOMICS, 29:7, 869-878, DOI: 10.1080/00140138608967199

To link to this article: https://doi.org/10.1080/00140138608967199

Published online: 30 May 2007.

ERGONOMICS, 1986, VOL. 29, NO. 7, 869–878

Isometric and isokinetic testing of lifting strength of males in teamwork

By WALDEMAR KARWOWSKI

Department of Industrial Engineering, Speed Scientific School, University of Louisville, Louisville, Kentucky 40292, U.S.A.

and ANIL MITAL

Ergonomics Research Laboratory, University of Cincinnati, Cincinnati, Ohio 45221, U.S.A.

Keywords: Strength; Lifting; Teamwork; Testing.

Additivity of static (isometric) and dynamic (isokinetic) strengths for teams of two and three males was evaluated. Six healthy college students participated in the laboratory experiment. The isometric strength evaluations consisted of four standard measures: arm, stooped back, leg, and composite, while the dynamic lift strength and dynamic back extension strength were used in isokinetic strength testing. In addition to individual strengths, the two-man strengths (15 teams for each of the six strengths) and the three-man strengths (20 teams for each of the six strengths) were tested. With the exception of the isometric leg strength for the team of two, and the isometric arm strength for the team of three, the team strengths were significantly lower ($P < 0{\cdot}01$) than the respective sums of the individual strengths of team members. On the average, the isometric strengths were approximately 94% of the sums of corresponding individual strengths for the team of two males. For the team of three males, the team isometric strengths averaged only 90% of the sum of individual strengths, with the exception of arm strength. The isokinetic strengths for the teams of two and three males accounted only for about 68 and 58% of the respective sums. The above results, indicating that human isometric and isotonic lifting strengths are not additive, suggest that the lifting capability of males in teamwork would be reduced as the number of team members increases.

1. Introduction

The determination of human strength exertion capabilities is an important consideration in the development of ergonomic guidelines for pre-employment screening of workers performing manual materials handling jobs (NIOSH 1981). Such jobs are a major source of musculoskeletal injuries in the United States and Europe and, despite recent advances in work automation, are still present in various industries (National Safety Council 1983, Taber 1982, Davies 1985).

Methods for measuring and predicting isometric and isokinetic (or isoinertial) strengths have already been developed to allow matching of muscular capabilities of workers with the force requirements of a particular job. It is also widely believed that such testing is necessary and can be carried out safely, reliably, and easily (Kraus 1967, Caldwell *et al.* 1974, Chaffin 1975, Chaffin *et al.* 1977, Garg *et al.* 1980, Keyserling *et al.* 1980, Mital and Ayoub 1980, Pytel and Kamon 1981, Kamon *et al.* 1982, Mital and Manivasagan 1982, 1984, Kroemer 1983, 1985, Mital 1984 a, Griffin *et al.* 1984, Mital *et al.* 1985). The measurements can also be successfully used to determine the maximum

permissible and maximum acceptable levels of loads that can be lifted safely in the vertical, horizontal, or transverse planes (Kamon *et al.* 1982, Mital and Karwowski 1985).

Generally, in the situations encountered in industrial settings, a single person can manage to handle objects. Occasionally, however, the objects are too heavy or bulky to be handled by only one person and two, or even three, workers might be needed to complete the assignment. This usually happens when mechanical aids are not easily available and/or their use is prevented by their size, workplace geometry or location of the object. The problem is not confined to manufacturing industries only. Instances when teamwork, in addition to individual lifting action, is needed are also frequently encountered in service, construction, health and agricultural industries.

As shown in the past, muscular strength plays an important role in establishing norms for one-person lifting action (Whitney 1958, Poulsen and Jorgensen 1971, Pedersen and Staffeldt 1972, Yates *et al.* 1980, Mital and Ayoub 1980, Kamon *et al.* 1982). It is logical to expect, therefore, that muscular strength would be equally important, if not more so, in establishing work limits for multiple worker tasks, and yet only sketchy information is available on the magnitude of human strength capabilities in teamwork. According to Davies (1972) it is unlikely that each person in a team would exert his maximum force at exactly the same time, of the total lifting force at any given time is unlikely to be the sum of the maximum individual lifting strengths of the team members. Kroemer (1974) suggested that when two or three people are engaged in simultaneous pushing, push force recommendations for single person should be doubled or tripled. He did not, however, substantiate his statement. Neither study provides any data proving or disproving the additivity concept for manual lifting strengths. A review of the published literature also failed to reveal any work dealing with the additivity of either lifting strength or lifting capability.

Since it is important for teamwork to relate individual worker strength to the total strength of the team, the main objective of this study was to determine whether the respective isometric and isokinetic lifting strengths of individuals could be added to determine total strength of teams of two and three males.

2. Methods

2.1. *Subjects*

Eight healthy male college students voluntarily participated in the laboratory experiment. An effort was made to select individuals who knew each other in order to ensure a high level of cooperation in team trials. All subjects were given a medical examination and were judged to be in good health. Two of the original eight subjects dropped out at early stages of the study for personal reasons so the final sample size was reduced to six subjects.

The subjects were informed of the purpose of the study, familiarized with the experimental setup, and informally trained in techniques for strength exertions. Each subject read and signed an informed consent form prior to his participation in the experiment. The subjects were paid on an hourly basis and were asked to avoid excessive indoor or outdoor physical activities, besides the project, that could lead to injury and possibly halt their further participation in the project.

Before assigning individuals to different teams, their individual isometric and isokinetic strengths and anthropometric characteristics were recorded. The mean, standard deviation, and range for each parameter measured are given in table 1. The

Table 1. Anthropometric measurements (cm) of the sample population ($n=6$).

Variable	Mean	S.D.	Range
Age (years)	24	1·7	21–16
Weight (kg)	79·7	19·4	58·9–115·6
Height	180·0	6·7	171·6–189·0
Acromial height	149·6	6·4	142·1–159·9
Standing illiac crest height	105·0	4·7	98·3–110·6
Arm span length	180·6	7·6	171·5–192·4
Forearm length	49·0	3·6	43·5–53·2
Shoulder breadth	45·0	4·6	39·6–50·1
Knee height	55·7	3·2	51·3–61·4
Chest circumference	102·3	9·3	88·9–118·1
Biceps flexed circumference	34·7	3·5	29·8–40·6
Biceps relaxed circumference	31·9	3·7	26·7–38·1
Calf circumference	36·6	3·8	30·5–41·9
Thigh circumference	55·0	5·4	47–61
Abdominal circumference	89·9	19·6	66·7–124·5
Grip strength (kg)	46·8	6·8	38·0–56·5

body size and isometric strength values of the sample are comparable to those of the industrial population (Mital 1984 b).

The subjects were instructed to wear comfortable work clothing of their choice.

2.2. *Experimental procedures*

2.2.1. *Individual strength measures*

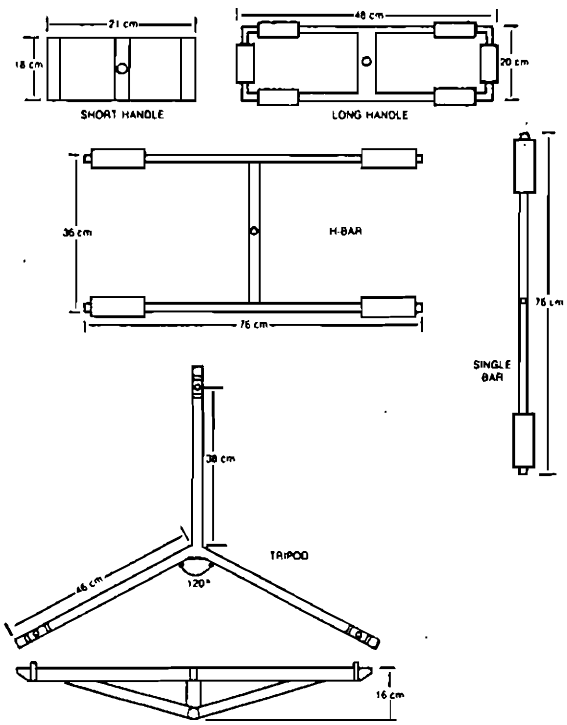
The isometric strength testing was performed according to the widely accepted procedures recommended by Caldwell *et al.* (1974) and Chaffin (1975). The Caldwell Regimen (Caldwell *et al.* 1974) was employed, and the subjects were asked to build up to their maximum exertions within about 2 seconds and maintain a steady maximal level of exertion for about 3 seconds. The verbal countdown with one-second intervals: −3, −2, −1, start, 1, 2, 3, 4, 5, stop, proposed by Kroemer and Marras (1981) was used, but no emotional appeals were made (Rube and Secher 1981).

The isometric strength evaluations consisted of four measures: the arm strength (A), stooped back strength (SB), leg strength (L), and composite strength (C). A *short handle* (1·4 kg) was used to measure C, *long handle* (2·2 kg) to measure A and SB, and *single bar* (1·3 kg) to measure L. The detailed description of the above handles (Ayoub *et al.* 1977) is given in the figure. The diameter of all handles was 3·85 cm including 0·20 cm thick padding.

In each case, peak forces exerted were recorded in all measurements made (Kroemer and Marras 1981). This was done so as to use the uniform measure of strength in both isometric and isokinetic testing procedures (Chaffin *et al.* 1977, Pytel and Kamon 1981).

The isokinetic strength testing procedure proposed by Pytel and Kamon (1981) was used to measure dynamic lifting strengths (DL) and dynamic back extension strengths (DBE). A Mini-Gym Model Super II was utilized for that purpose. The maximum speed of isokinetic action was set at about 0·75 m s^{-1} (Mital and Karwowski 1985). An electronic tachometer was used for speed calibration. The subjects were asked to pull on the handle as hard and as quickly as they could, but without jerking it.

For each of the isometric and isokinetic strength tests, two trials were made and the mean peak force exerted was recorded. The sequence of measurements was randomized



Handles used in the study.

for each subject and a rest of at least 4 minutes was provided between trials. The isometric and isoinertial strength tests were performed on different days.

2.2.2. *Team strength measures*

In order to measure isometric and isokinetic strengths of the teams of two and three males, special handles were designed and constructed. The figure shows the handles used in the study. An *H-bar* handle weighing 3·5 kg was used in testing the two-man team isometric stooped back strength (SB) and leg strength (L). In SB measurements each subject held the end of each bar and took position at the openings provided at the end. During L measurements, each subject held just one bar. The procedure was similar to the individual measurement. The H-bar was also used for measuring two-man team DL and DBE values.

For measuring two-man isometric composite (C) and arm (A) strengths, the equipment used previously for the individual measurements (Chaffin 1975), respectively, was modified. The long handle was padded on the sides and used for measuring team isometric composite (C) strengths. When measuring an A strength of the team, the subjects faced each other and used the same *long handle* as they used in the individual strength exertion trials.

In order to measure strengths of teams of three males, a *tripod* handle (weighing 8·85 kg) was constructed (figure). Special mountings were provided so that each subject could use the short handle, long handle, or the single bar, just as in the case of individual measurements. The tripod, with appropriate handles mounted on it, was utilized in both isometric and isokinetic strength measurements of three-man teams.

The measurement procedure consisted of the same evaluations as applied in individuals and two-man team testing. The only difference was in the time allowed for exertions. The countdown was as follows: -2, -1, start, 1, 2, 3, 4, 5, 6, 7, stop. Only 2 seconds were allowed for preparation to avoid static fatigue that could develop while getting ready for the test itself. A time period of up to 4 seconds was allowed for each person in the team to achieve the steady state.

To ensure that each member of the team was recruiting the same muscle groups as applied in the individual measures (Grieve 1984, Karvonen 1985), and to eliminate potential disadvantages due to differences in stature among the team members, 0·65 cm-thick wooden boards were used to accommodate shorter subjects. As many as six boards were used in order to provide similar statures and postures for all subjects.

Two trials were performed for each of the six strengths exerted in both single and teamwork tests (four isometric and two isokinetic). The teams were trained to avoid any jerking. Totals of 328 and 164 data points were recorded for the isometric and isokinetic strength test, respectively. All the strength values were adjusted for the inertial forces due to the weight of the handles used. The experimental protocol required that if the two readings, for any strength measure, differed by more than 10%, a third trial would be made and the two closest readings would be used in data analysis. As it turned out, no two readings for any set of trials, either individual or teamwork, differed by more than 6%.

3. Results and discussion

3.1. *Individual strength measures*

The values of isometric and isokinetic strength measures for the sample population are given in table 2.

3.2. *Strength measures for teams of two males*

Actual strength values, corresponding sums of individual strengths of the two-man team members, and percentage differences are given in table 3. The differences were defined as (sum − actual strength)/sum × 100%.

3.3. *Strength measures for teams of three males*

Actual strength values, corresponding sums of individual strengths of the three-man team members, and percentage differences are given in table 4.

3.4. *Additivity of isometric and isokinetic strengths in teamwork*

A paired t-test analysis (table 5) revealed that with the exception of the isometric leg strength for a team of two males, and the isometric arm strength for a three-man team,

Table 2. Isometric and isokinetic strengths (N) of the sample population.

Variable	Mean	S.D.	Range
Isometric arm strength (A)	438·5	21·6	402–461
Isometric stooped back strength (SB)	1006·5	171·6	745–1266
Isometric leg strength (L)	1480·3	263·9	1108–1923
Isometric composite strength (C)	1231·2	154·0	961–1481
Isokinetic lift strength (DL)	861·3	96·1	706–1020
Isokinetic back extension strength (DBE)	683·7	76·5	559–785

Table 3. Isometric and isokinetic strengths (N) for a team of two males.

Variable	Mean	S.D.	Range
Isometric arm strength (A)			
Team	813·8	123·5	608–1017
Sum	877·6	25·4	825–919
Difference (%)	7·3	13·3	−12·8–29·7
Isometric stooped back strength (SB)			
Team	1883·9	227·7	1389–2354
Sum	2011·3	204·6	1620–2379
Difference (%)	5·5	13·7	−20·5–33
Isometric leg strength (L)			
Team	2814·0	375·0	2126–3485
Sum	2930·7	302·4	2442–3587
Difference (%)	3·1	16	−36–31
Isometric composite strength (C)			
Team	2312·1	286·0	1829–2934
Sum	2458·3	186·9	2126–2752
Difference (%)	5·7	16·3	−23·7–22·5
Isokinetic lift strength (DL)			
Team	1146·3	103·3	963–1398
Sum	1722·7	114·1	1509–1931
Difference (%)	33·4	5·2	18·3–41·4
Isokinetic back extension strength (DBE)			
Team	929·0	74·5	755–1059
Sum	1364·3	91·9	1216–1536
Difference (%)	31·8	5·5	20–43

Table 4. Isometric and isokinetic strengths (N) for a team of three males.

Variable	Mean	S.D.	Range
Isometric arm strength (A)			
Team	1384·3	166·7	1025–1691
Sum	1316·5	26·8	1265–1367
Difference (%)	−5	11·5	−24·5–22
Isometric stooped back strength (SB)			
Team	2678·5	313·6	2024–3298
Sum	3016·9	216·2	2637–3396
Difference (%)	10·7	12·6	−13–30·3
Isometric leg strength (L)			
Team	4066·4	536·7	2854–5279
Sum	4433·3	340·5	3791–5074
Difference (%)	7·7	14·7	−19·3–32
Isometric composite strength (C)			
Team	3268·7	381·4	2637–4329
Sum	3687·4	197·5	3347–4027
Difference (%)	11·4	8·4	−7·5 – 27·8
Isokinetic lift strength (DL)			
Team	1558·6	133·4	1283–1838
Sum	2584·0	120·5	2366–2801
Difference (%)	39·7	3·5	33–46·5
Isokinetic back extension strength (DBE)			
Team	1136·7	81·4	1007–1345
Sum	2045·1	97·9	1869–2224
Difference (%)	44·4	3·5	37·2–51·9

Table 5. Results of the paired *t*-tests for the differences between the sums and teams strength measures for two (T2) and three (T3) males.

Strength measure	Team	d.f.	*t*	*P*	Team strength as a percentage of the sum of individual strengths: Mean	S.D.	Range
Isometric arm strength (A)	T2	19	2·99	$<0·01$	92·6	13·3	70–113
	T3	29	$-2·80$	$<0·01$	105	11·5	78–125
Isometric leg strength (L)	T2	19	1·43	NS	96·8	16·0	69–136
	T3	29	3·54	$<0·01$	92·3	14·7	68–119
Isometric stooped back strength (SB)	T2	19	2·44	$<0·05$	94·5	13·6	67–120
	T3	29	5·48	$<0·0001$	88·6	8·4	69–113
Isometric composite strength (C)	T2	19	2·96	$<0·01$	94·3	11·6	77·4–124
	T3	29	8·48	$<0·0001$	88·5	8·4	72–107
Isokinetic lift strength (DL)	T2	19	29·60	$<0·001$	66·6	5·2	58·5–82
	T3	29	76·20	$<0·0001$	60·3	3·5	53–67
Isokinetic back extension strength (DBE)	T2	19	26·30	$<0·001$	68	5·5	57–80
	T3	29	63·10	$<0·0001$	55·6	3·5	48–62

NS: Not significant at 10% or greater level of significance.

the actual team strengths were significantly lower ($P<0·01$) than the corresponding sums of individual's strengths.

In general, these differences were greater for isokinetic strength than for isometric strength measures. The actual isometric arm, back extension and composite strengths for a team of two males, on the average, accounted for approximately 95% of the respective sum. The isometric leg strength of teams of two males was approximately 97% of the sum of individual's leg strengths. In comparison, dynamic strengths of two-male teams were only 67·5% of the sums.

For teams of three males, the isometric leg, back extension and composite strengths of the team, on the average, accounted for approximately 90% of the corresponding sums of individual strengths. Interestingly, the average actual arm strength of the team was significantly greater (105% of the sum) than the sum ($P<0·01$). The differences between actual and sum strengths for teams of three males were, however, much more profound for isokinetic strengths. The actual strengths of the teams accounted, on the average, for only 58% of the corresponding sums.

Some of the reasons for the above results would be lack of perfect coordination between the subjects in building up the maximal levels of exertions, as well as possible deviation from the vertical plane of the actual force application due to differences in individual strengths of the team members. As indicated by Whitney (1958), when the lifting force is exerted, some readjustment of the lifting posture often occurs, and the line of action of the body's weight itself changes. It is reasonable to assume that such phenomena would be considerably more pronounced in teamwork.

As shown in the literature (Pytel and Kamon 1981, Kamon *et al.* 1982, Kroemer 1983, 1985, Mital and Karwowski 1985), isokinetic strengths can be used to predict the maximum weights of lift acceptable to people. Since the peak isokinetic strength closely approximates actual maximum lifting capability of individuals (Pytel and Kamon 1981, Mital and Karwowski 1985), it is logical to presume that the maximum lifting

capability of males in teamwork will also be proportionately less than the sum of the corresponding lifting capabilities of the team members.

It should be noted that in the present study shorter subjects were always accommodated. In real-life situations people of different statures make up a team and height accommodations are not possible. Often, the height differences are due to the workplace layout, for instance when carrying objects on stairs. Therefore, the values of strengths given in table 5 should be considered the upper limits of strength that could be generated by teams of two or three males when members of the team are of equal, or near equal, height. It is reasonable to expect that in reality the strength of a team of two or three males would even be lower than the values shown in table 5.

4. Conclusions

The results of this study indicate that isometric and isokinetic strengths of males are not additive, and in general, the actual strength values for teams of two or three men are significantly lower than the corresponding sums of individual strengths. On the average, the isometric strength of a team of two males is approximately 94% of the sum of their individual strengths. As the number of workers in the team increases to three, the team isometric strengths decline to about 90% of the total strength.

Isokinetic strengths of teams of two males are, on the average, only 68% of the total of individual isokinetic strengths. When a third member is added to the team, the actual strengths exerted by the team account only for approximately 58% of the summed up strength. Since the isokinetic strength decreases as the number of workers increases from one to two to three, it is also logical to expect that the maximum lifting capability of teams of two or three men will also decline proportionately.

Acknowledgments

This study was supported by a grant from the Graduate Research Council, University of Louisville (UHSC 50-84).

The authors also wish to acknowledge Dr. J. W. Yates of the University of Louisville for his assistance in carrying out the experimental part of the project.

On évalué les propriétés d'additivité des forces statiques (isométriques) et dynamiques (isotonique ou isocinétique) dans des groupes de deux et trois sujets hommes. Six étudiants bien portants ont participé à l'expérience en laboratoire. Les évaluations de la force isométrique ont porté sur quatre mesures prises sur le bras, le dos courbé, la jambe et la composition des trois, alors que la force de levage dynamique et la force d'extension dynamique du dos ont été utilisées pour èprouver la force isotonique. Outre les forces individuelles, on a testé les forces pour les paires (15 paires pour chacune des six forces) et les forces pour les équipes de trois (20 équipes pour chacune des six forces). A l'exception de la force isométrique de la jambe pour l'équipe de deux hommes, les forces par équipe étaient significative ($P<0{,}01$) plus basses que les sommes respectives des forces individuelles. En moyenne, les forces isométriques représentaient environ 94% de la somme des forces individuelles pour les équipes de deux hommes. Pour les équipes de trois hommes, ce pourcentage était réduis à 90%, dauf pour la force des bras. Les forces isocinétiques pour les équipes de deux et de trois hommes ne représentaient que 68% et 58% de leurs sommes respectives. Les résultats indiquant que les forces de levage isométriques et isotoniques ne sont pas additives suggèrent que les capacités de levage des sujets travaillant en équipe diminuent lorsque le nombre d'individus dans l'équipe augmente.

Die Additivität von statischen (isometrischen) und dynamischen (isometrischen oder isokinetischen) Kräften wurde für Gruppen von zwei und drei Männern ausgewertet. Sechs gesunde Collegestudenten nahmen an dem Laborexperiment teil. Die Auswertungen der isometrischen Kraft erfolgten für vier Standardmessungen: Armkraft, Kraft bei gebeugtem Rücken, Beinkraft und zusammengesetzte Kraft, während die dynamische Hebekraft und die dynamische Dehnungskraft des Rückens in dem Test der isotonischen Kraft benutzt wurde. Dazu wurden neben den individuellen Kräften die 'Zwei-Mann-Kräfte' (15 Gruppen für jede der sechs Kräfte) und die 'Drei-Mann-Krafte' (20 Gruppen für jede der sechs Kräfte) untersucht. Mit Ausnahme der isometrischen Beinkraft für die Gruppe von zwei Männern und der isometrischen Armkraft für die Gruppe von drei Männern waren die 'Gruppenkräfte' signifikant geringer ($P < 0{,}01$) als die jeweilige Summe der Individualkräfte der Gruppenmitglieder. Im Durschschnitt waren die isometrischen Kräfte für die Gruppe zwei Männern ungefähr 94% der Summe der korrespondierenden individuellen Kräfte. Für die Gruppe der drei Mãnner betrug die isometrische Kraft der Gruppe im Durchschnitt nur 90% der Summe der individuellen Kräfte, mit Ausnahme der Armkräfte. Die isokinetischen Kräfte für die Zwei-Mann und Drei-Mann-Gruppe berechneten sich auf ungeführ 68% und 58% der Einzelsumme. Die obigen Ergebnisse zeigen auf, daß die menschlichen isometrischen und isotonischen Hebekräfte nicht additiv sind und sie geben zu bedenken, daß sich die Hebekapazität von Männern innerhalb von Gruppenarbeit reduzieren wird, je höher die Anzahl der Gruppenmitglieder steigt.

静的（等尺性）筋力と動的（等張性あるいは等運動性）筋力の男性２名及び３名協同時の加法性の評価を行った。健康な大学生６名を実験室実験の被験者に用いた。等尺性筋力の評価は，腕，前傾の背中，脚，及びそれらを複合したものの４種類の標準的な測定値から成り，一方，動的持ち上げ力と動的背伸展力とを等張性筋力検査に用いた。個人の筋力の検査に加え，男性２名協同（６名から２名の組の全ての組合せ15組）の筋力と男性３名協同（６名から３名の全ての組合せ20組）の筋力を検査した。２名協同の等尺性脚力と３名協同の等尺性腕力を例外とし，協同時の力は組を構成する各個人の筋力を合計した値より有意に低い値を示した（$p < 0.01$）。平均して，２名協同の場合の等尺性筋力は個人の筋力の合計の約94%となり，３名協同の場合では，腕力を例外として個人の筋力の合計の90%までにしかならなかった。２名及び３名協同時の等張性筋力は個人の筋力の合計のそれぞれ68%と58%程度であった。以上の結果より，人間の等尺性持ち上げ筋力及び等張性持ち上げ筋力は加法的ではなく，男性の協同持ち上げ能力は構成人数が増すに従って減少するであろうことが示された。

References

AYOUB, M. M., DEIVANAYAGAM, S., and BAKKEN, G. M., 1977, A preliminary manual for anthropometric and strength measurements. Unpublished Technical Report, Texas Tech. University, Lubbock, TX.

CALDWELL, L. S., CHAFFIN, D. B., DUKES-DOBOS, F. N., KROEMER, K. H. E., LAUBACH, L. L., SNOOK, S. H., and WASSERMAN, D. E., 1974, A proposed standard procedure for static muscle strength testing. *American Industrial Hygiene Association Journal*, **35**, 201.

CHAFFIN, D. B., 1975, Ergonomics guide for the assessment of human static strength. *American Industrial Hygiene Association Journal*, **36**, 505–11.

CHAFFIN, D. B., HERRIN, G. D., KEYSERLING, W. M., and FOULKE, J. A., 1977, Pre-employment strength testing. Final report, DHHS (NIOSH) Contract No. CDC-99-74-62, U.S. Government Printing Office, Washington, D.C.

DAVIES, B. T., 1972, Moving loads manually. *Applied Ergonomics*, **3**, 190–94.

DAVIES, P., 1985, Special Issue: Industrial Back Pain in Europe. *Ergonomics*, **28**, 1–442.

GARG, A., MITAL, A., and ASFOUR, S. S., 1980, A comparison of isometric strength and dynamic lifting capability. *Ergonomics*, **23**, 23–27.

GRIEVE, D. W., 1984, The influence of posture on power output generated in single pulling movements. *Applied Ergonomics*, **15**, 115–7.

GRIFFIN, A. B., TROUP, J. D. G., and LLOYD, D. C. E. F., 1984, Testing of lifting and handling capacity, their repeatability and relationship to back symptoms. *Ergonomics*, **27**, 305–20.

KAMON, E., KISER, D., and PYTEL, J. L., 1982, Dynamic and static lifting capacity and muscular strength of steelmill workers. *American Industrial Hygiene Association Journal*, **43**, 853–57.

KARVONEN, M. J., 1985, Effects of temporal patterns of work on lifting and handling capacities. *Ergonomics*, **28**, 177–81.

KEYSERLING, W. M., HERRIN, G. D., CHAFFIN, D. B., ARMSTRONG, T. J., and FOSS, M. L., 1980, Establishing an industrial strength testing program. *American Industrial Hygiene Association Journal*, **41**, 730–36.

KRAUS, H., 1967, Prevention of low back pain. *Journal of Occupational Medicine*, **9**, 555–59.

KROEMER, K. H. E., 1974, Horizontal push and pull forces. *Applied Ergonomics*, **5**, 94–102.

KROEMER, K. H. E., 1983, An isoinertial technique to assess individual lifting capability. *Human Factors*, **25**, 493–506.

KROEMER, K. H. E., 1985, Testing individual capability to lift material: repeatability of a dynamic test compared with static testing. *Journal of Safety Research*, **16**, 1–7.

KROEMER, K. H. E., and MARRAS, W. S., 1981, Evaluation of maximal and submaximal static muscle exertions. *Human Factors*, **23**, 643–53.

MITAL, A., 1984 a, Prediction of human static and dynamic strength by modified basic GMDH algorithm. *IEEE Transactions on Systems, Man and Cybermetics*, **14**, 773–76.

MITAL, A., 1984 b, Maximum weights of lift acceptable to male and female industrial workers for extended work shifts. *Ergonomics*, **27**, 1115–26.

MITAL, A., AGHAZADEH, F., and RAMANAN, S., 1985, Use of non-linear polynomials to predict human dynamic strengths. *International Journal of Computers and Industrial Engineering*, **9**, 371–77.

MITAL, A., and AYOUB, M. M., 1980, Modeling of lifting capacity and isometric strength. *Human Factors*, **22**, 285–90.

MITAL, A., and KARWOWSKI, W., 1985, Use of simulated job dynamic strength (SJDS) in screening workers for manual lifting tasks. In: *Proceedings of the Human Factors Society 29th Annual Meeting*, Santa Monica, CA, pp. 513–516.

MITAL, A., and MANIVASAGAN, I., 1982, Application of a heuristic technique in polyomial identification. *Proceedings of the International Conference on Cybernetics and Society*, IEEE Systems, Man and Cybernetics Society, 347–53.

MITAL, A., and MANIVASAGAN, I., 1984, Development of non-linear polynomials in identifying human isometric strength behaviour. *International Journal of Computers and Industrial Engineering*, **8**, 1–9.

NATIONAL SAFETY COUNCIL, 1983, *Back Injury Prevention Through Ergonomics (Videotape)* (Chicago, Illinois).

NIOSH, 1981, *Work Practices Guide for Manual Lifting*. Technical Report, National Institute for Occupational Safety and Health, DHMS, NIOSH Publication No. 81–122 (Washington, D.C.: GOVERNMENT PRINTING OFFICE).

PEDERSEN, O. F., and STAFFELDT, E. S., 1972, The relationship between four tests of back muscle strength in untrained subjects. *Scandinavian Journal of Rehabilitation Medicine*, **4**, 175–81.

POULSEN, E., and JORGENSEN, K., 1971, Back muscle strength, lifting and stooped working postures. *Applied Ergonomics*, **2**, 133–37.

PYTEL, J. L., and KAMON, E., 1981, Dynamic strength test as a predictor for maximal and acceptable lifting. *Ergonomics*, **24**, 663–72.

RUBE, N., and SECHER, N. M., 1981, Paradoxical influence of encouragement on muscle fatigue. *European Journal of Applied Physiology*, **46**, 1–7.

TABER, M., 1982, Reconstructing the scene, back injury. *Occupational Health and Safety*, **51**, 16–22.

WHITNEY, R. J. 1958, The strength of lifting action in man. *Ergonomics*, **1**, 101–28.

YATES, J. W., KAMON, E., RODGERS, S. H., and CHAMPNEY, P. C., 1980, Static lifting strength and maximal isometric voluntary contractions of back, arm and shoulder muscles. *Ergonomics*, **23**, 37–47.

Manuscript received 17 July 1985.
Final revision received and accepted 5 December 1985.